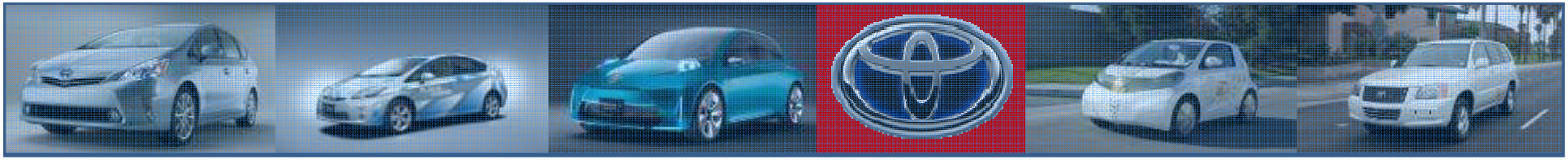
Future Transportation Trends and Challenges

SASHTO Partnering Conference

Robert Wimmer

Toyota Motor North America, Inc
August 23, 2011



Scope of Presentation

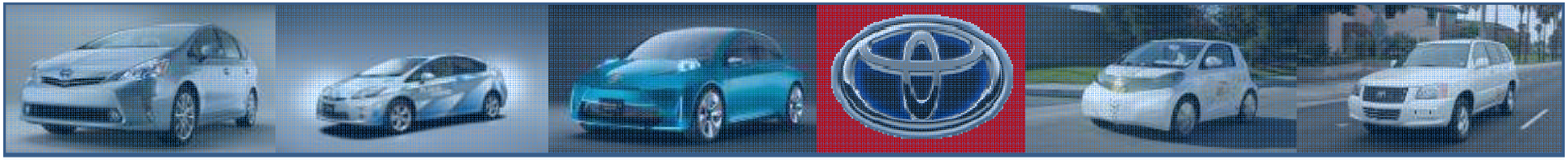
❶ Drivers of change

② Technology options

③ Consumer adoption factors

④ Other considerations

⑤ Conclusions & recommendations



Issues Driving Future Powertrain Development

Air Pollution

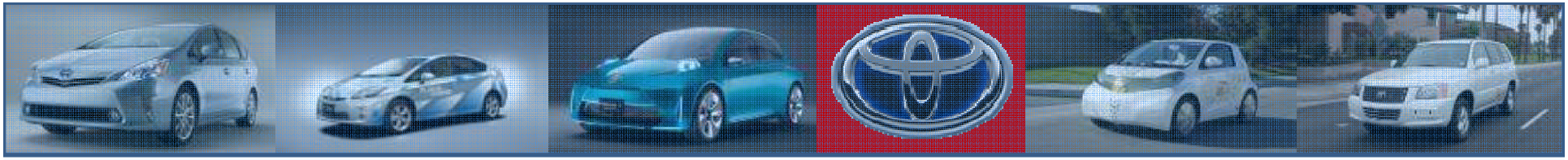
Declining Resources

Traffic Congestion

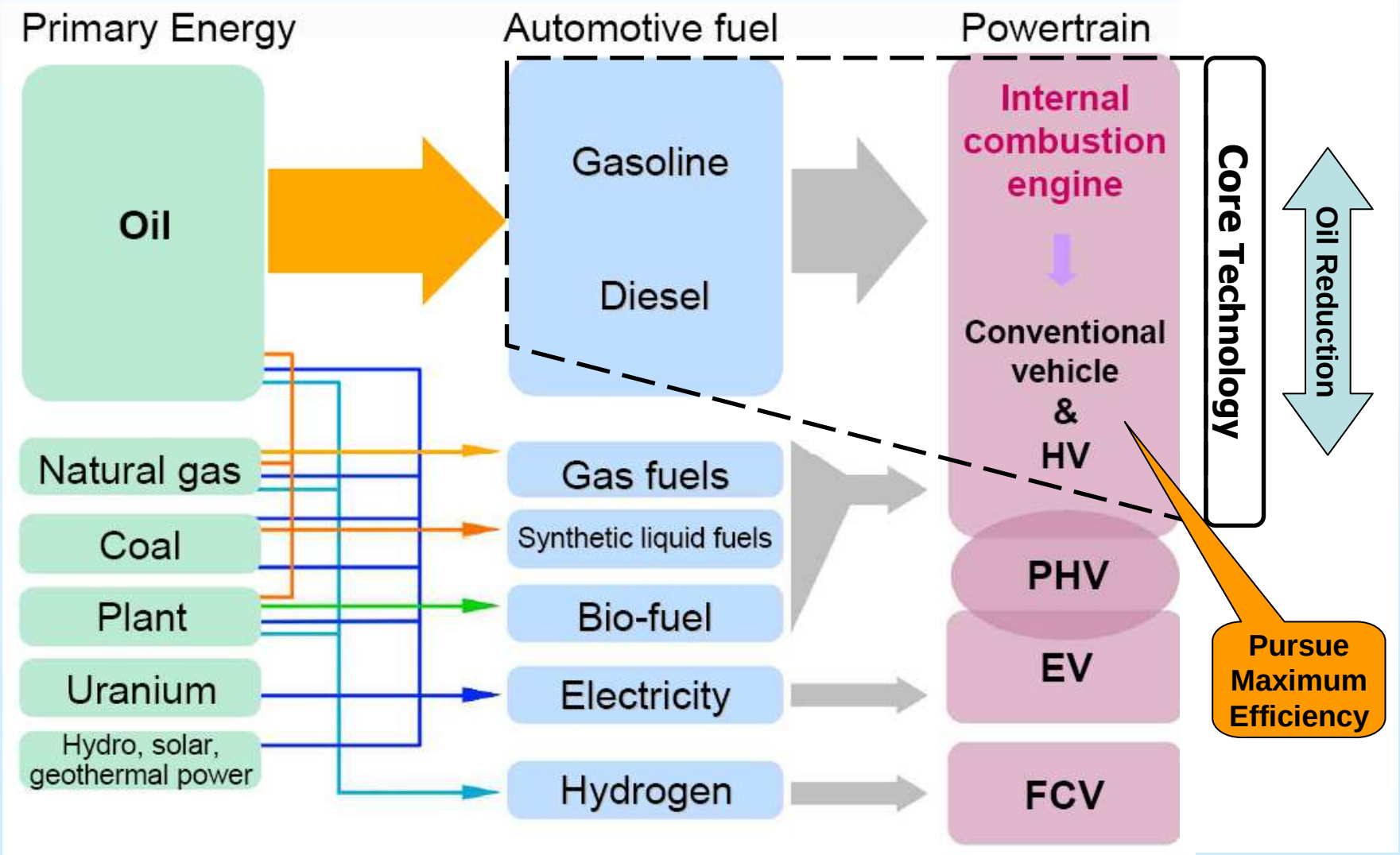
Climate Change

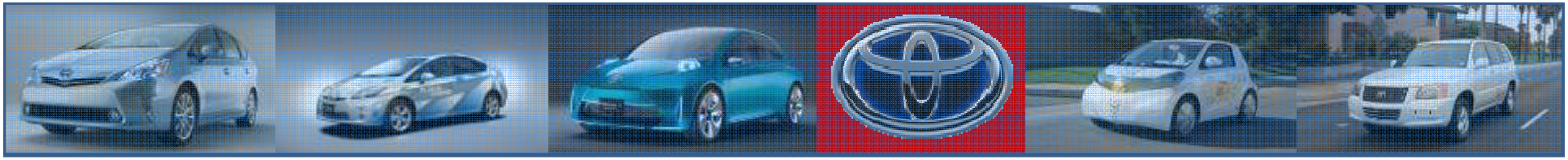
Regulations

Energy Security

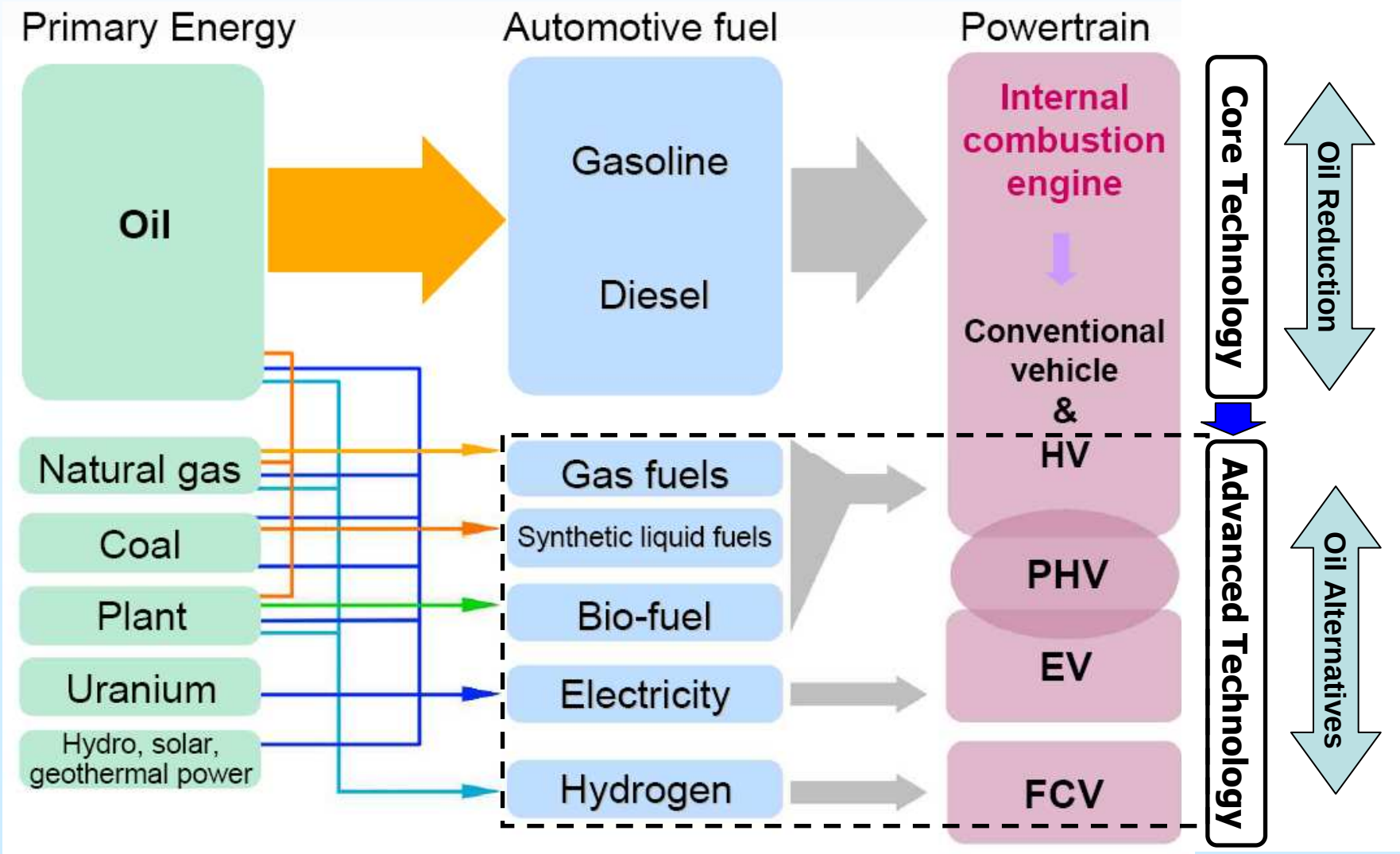


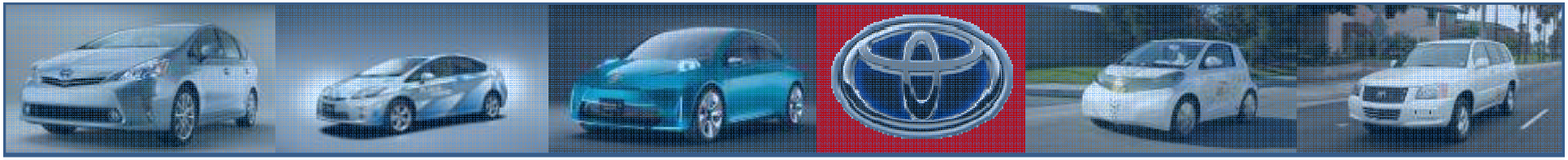
Diversification of Fuels & Powertrains





Diversification of Fuels & Powertrains





Scope of Presentation

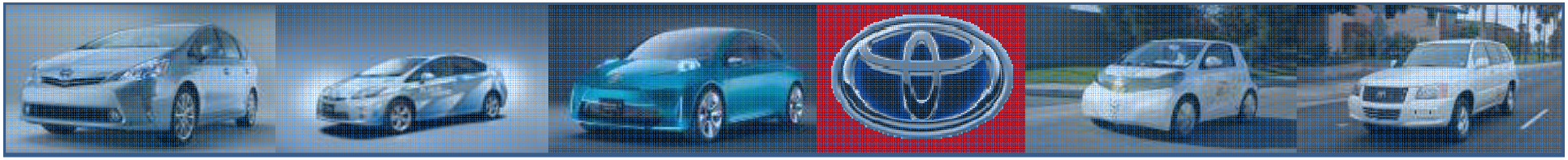
① Drivers of change

❷ Technology Options

③ Consumer adoption factors

④ Other considerations

⑤ Conclusions & recommendations



Advanced Technology Options

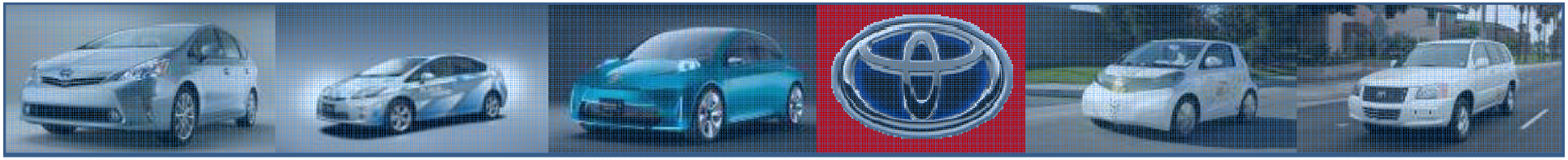
Battery Electric Vehicle (BEV)
[RAV4-EV]

Hybrid Electric Vehicle (HEV)
[Prius]

Fuel Cell Hybrid Electric Vehicle
[FCHV-adv]

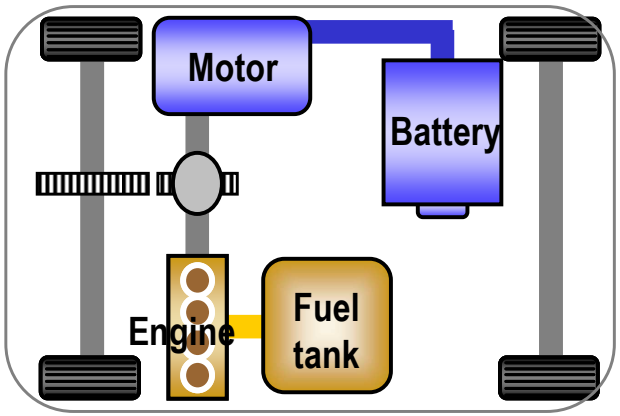
Plug-in Hybrid Electric Vehicle (PHEV)
[Prius PHEV]

Battery Electric Vehicle (BEV)
[FT-EV]



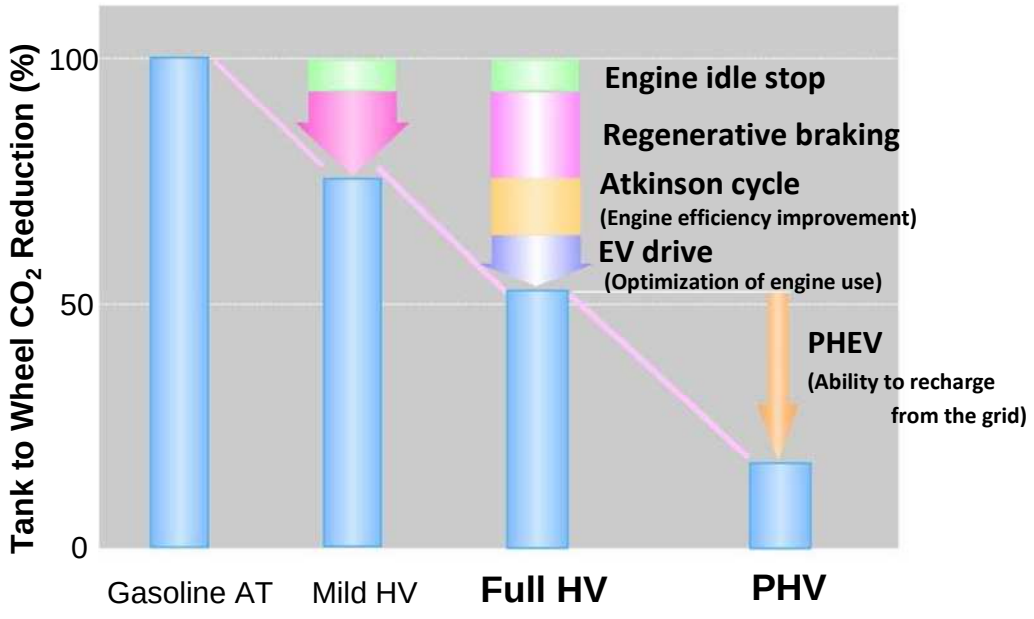
Hybrid is the Foundation

2012 Prius V

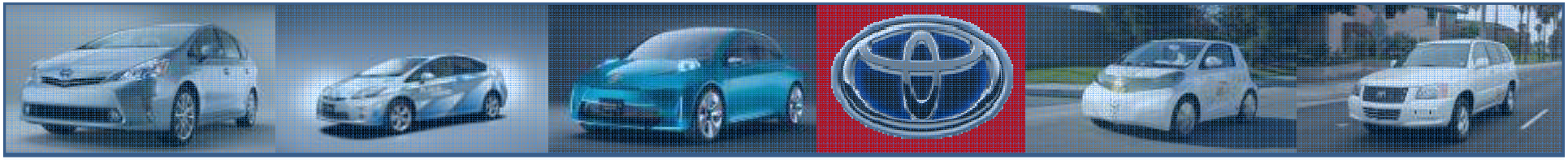


Hybrid Drivetrain

Potential Gains from Hybridization



Optimization of hybrid characteristics key to maximizing efficiency



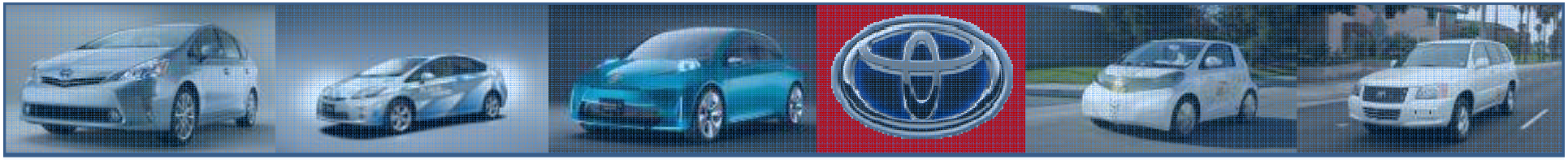
Hybrid Evolution




MODEL YEAR	1998 - 2000	2001 - 2003	2004 - 2009	2010 -
MARKET	JAPAN	USA, JAPAN	WORLDWIDE	WORLDWIDE
City Fuel Economy*	43 mpg	42 mpg	48 mpg	51 mpg
Hwy. Fuel Economy	41 mpg	41 mpg	45 mpg	48 mpg
Comb. Fuel Economy	42 mpg	42 mpg	46 mpg	50 mpg
0-60 MPH Accel	14.5 sec	12.5 sec	10.5 sec	9.8 sec
Emissions	LEV	SULEV	AT-PZEV	AT-PZEV
Size Class	Sub-Compact	Compact	Mid-Size	Mid-Size

*All fuel economy numbers of US spec vehicles based on current EPA rating system
Japan spec vehicle based on previous EPA system

Future evolution will balance cost reduction with performance improvement



Expansion of Toyota Hybrid Technology

Toyota

Lexus

<Past>

RX400h

<Present>

Prius

Camry Hybrid

Highlander Hybrid

Prius V

CT200h

RX450h

HS250h

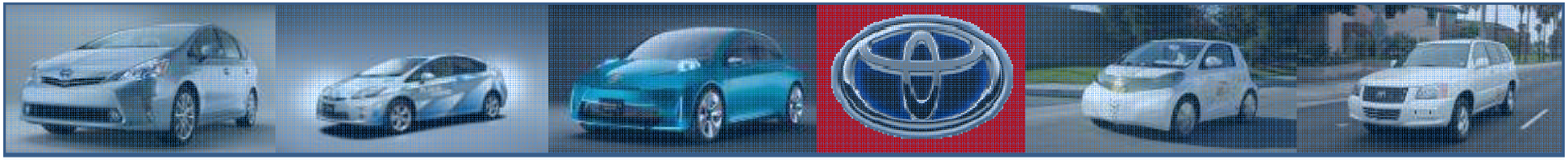
GS450h

LS600h

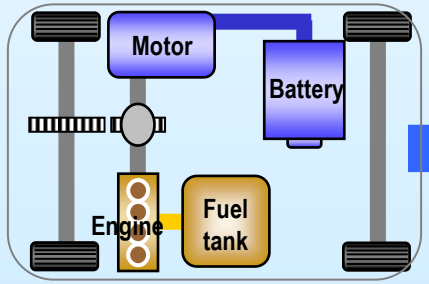
<Future>

Prius C

LF-Gh Concept



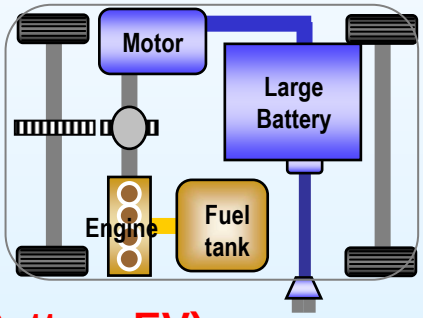
Hybrid is the Foundation



HV

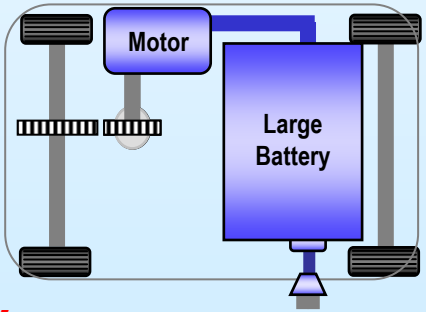
Energy saving
(Fuel economy improvement)

PHV



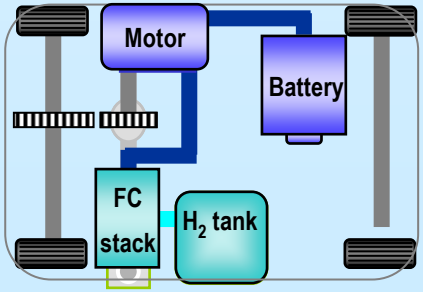
Zero CO_2 emissions
during inner city driving

EV (Battery EV)



Zero CO_2 emissions
during driving

FCHV (Hydrogen FCEV)

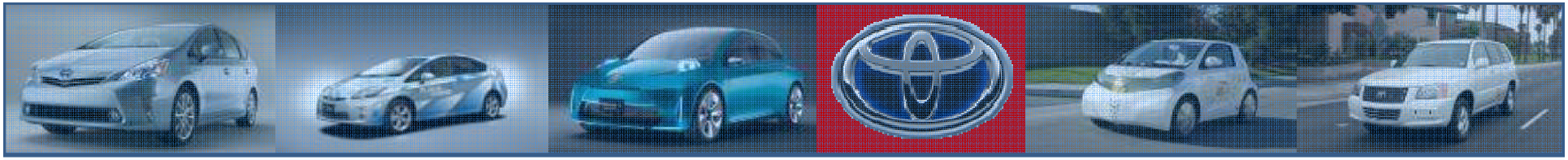


Issues

Cost
Battery durability

Cruising range
Charging time
Infrastructure
Cost
Battery durability

Infrastructure
Cost
Stack durability



PHEV

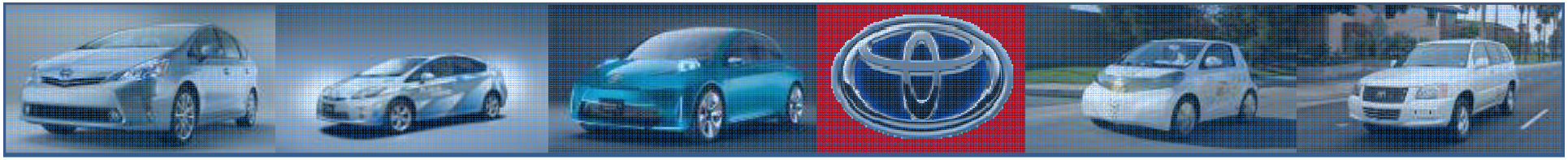
Battery Electric Vehicle (BEV)
[RAV4-EV]

Fuel Cell Hybrid Electric Vehicle
[FCHV-adv]

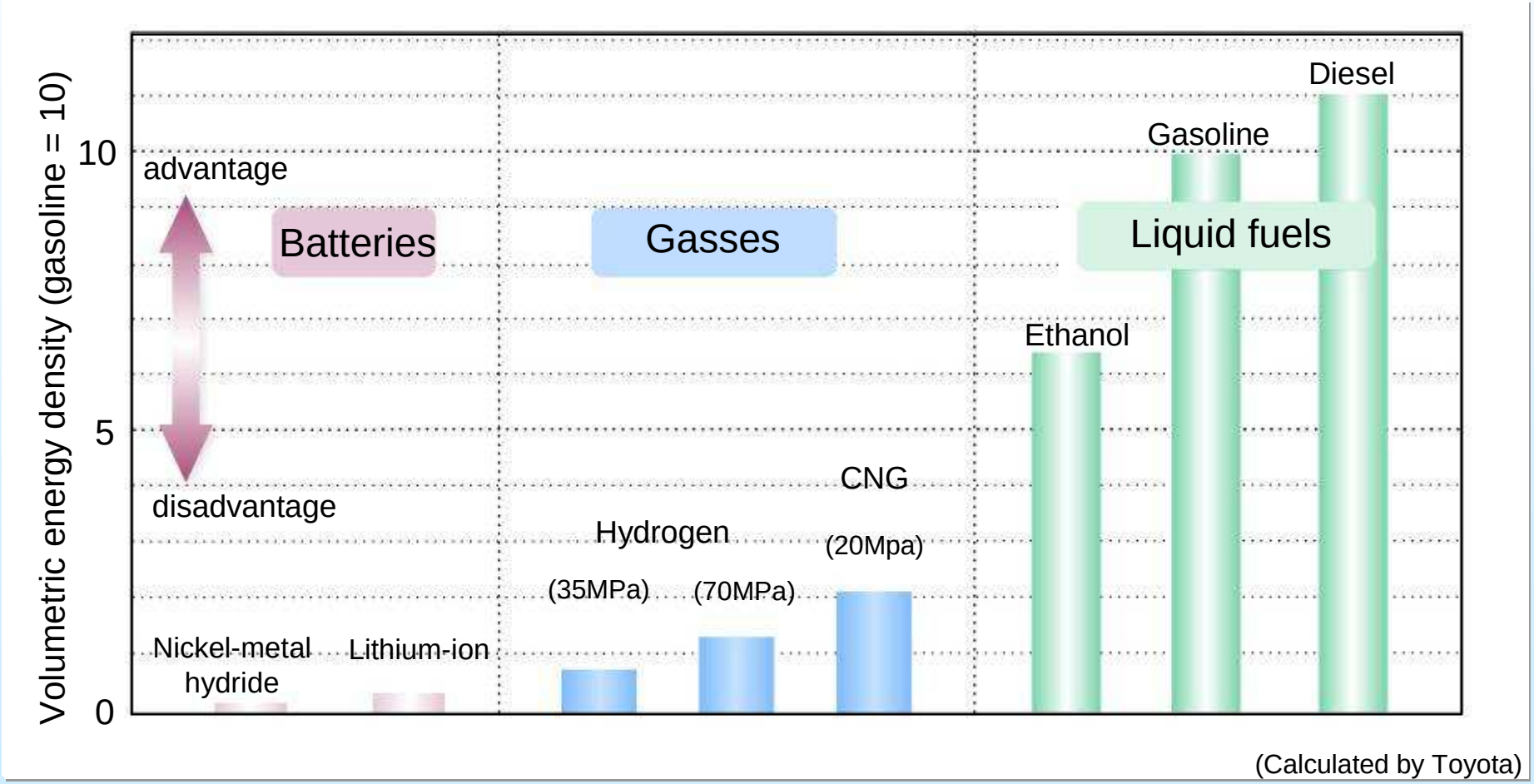
Hybrid Electric Vehicle (HEV)
[Prius]

Plug-in Hybrid Electric Vehicle (PHEV)
[Prius PHEV]

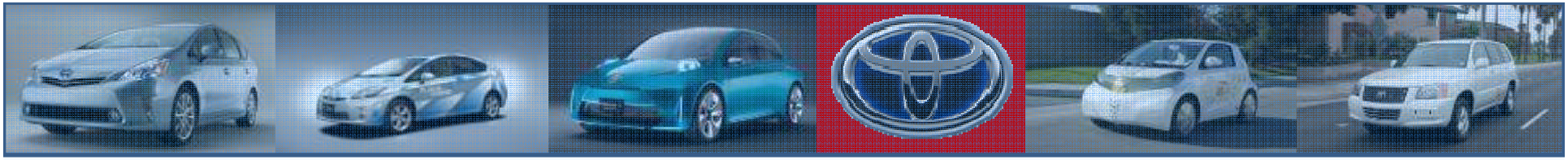
Battery Electric Vehicle (BEV)
[FT-EV]



Energy Density Comparison



Energy density of electricity is approx. 1/50 of gasoline



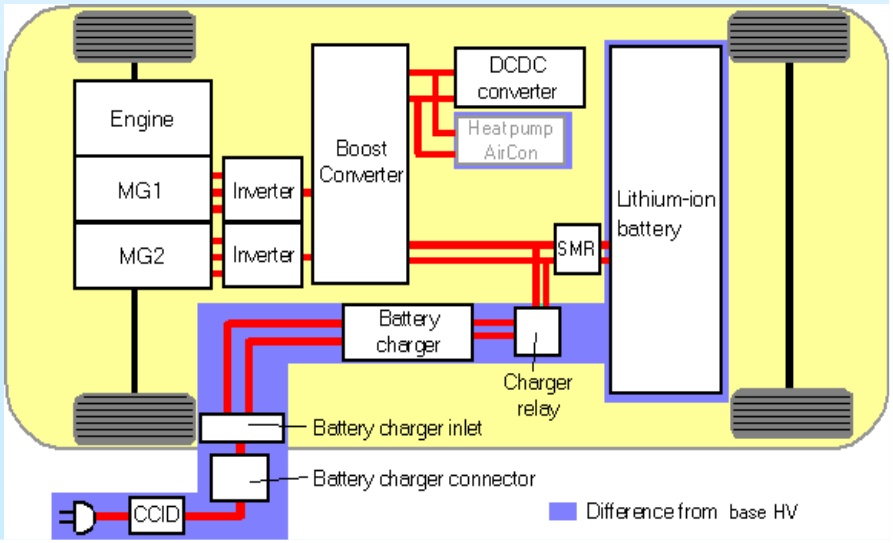
Prius PHEV

- 600 Vehicle global demonstration program
  - Gauge consumer acceptance and use patterns in various markets
- Consumer version available in 2012

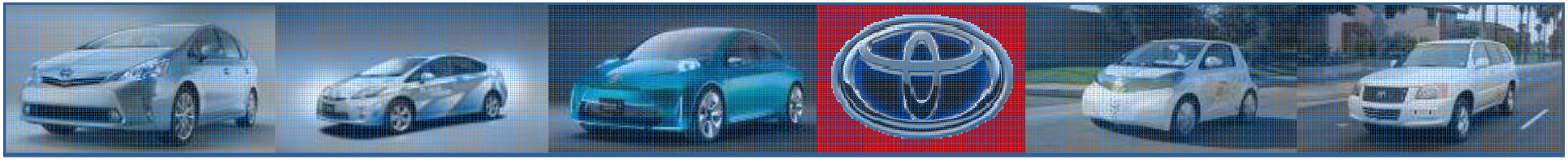
Minimum System Change from HV

2 Main Modifications
- High Power Lithium-Ion Battery
  - 13 mile AER
- 100V/240V Charger

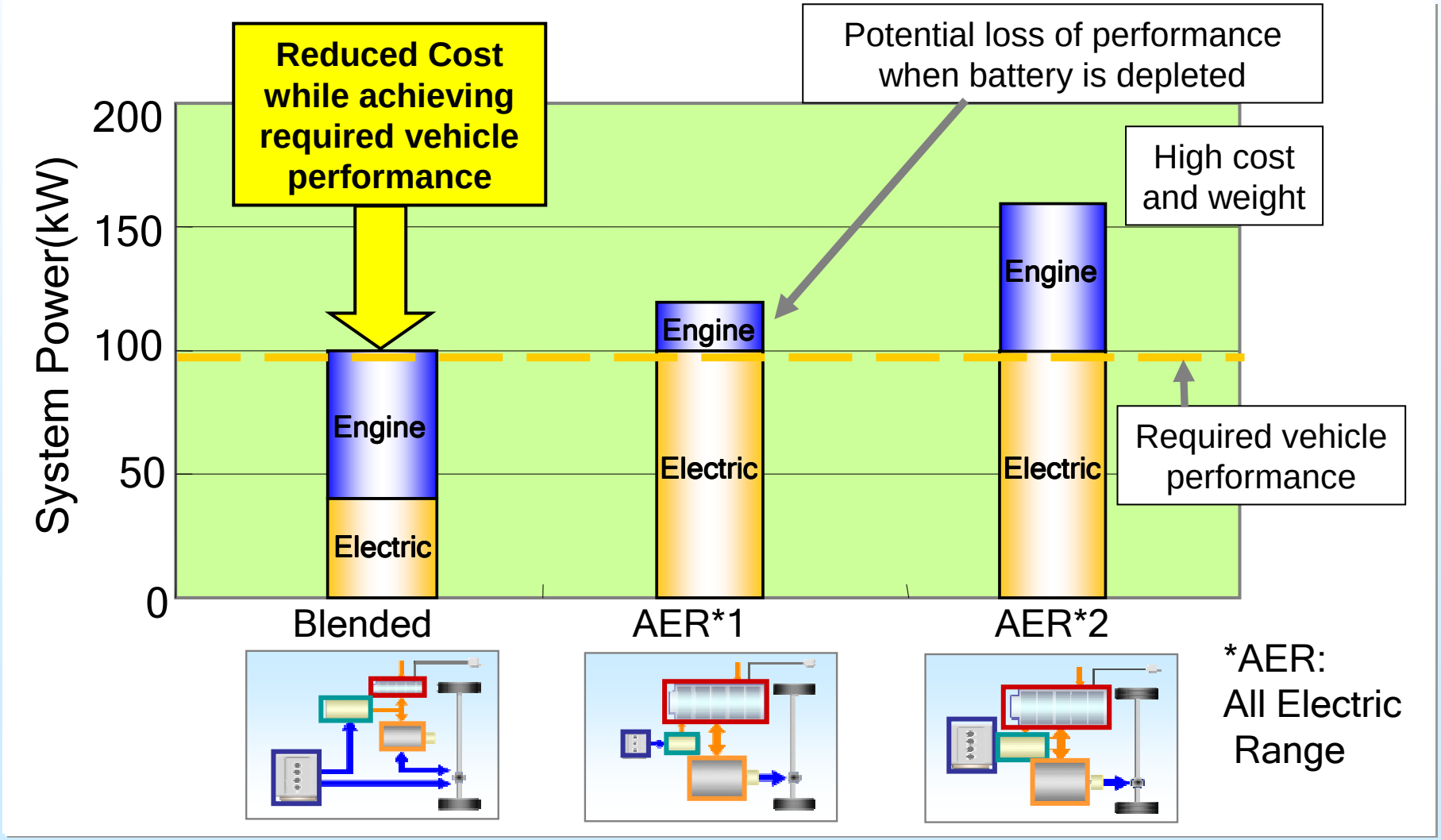
	Base HV	PHV
Engine	1.8L Atkinson & Cooled EGR 73kW	←
Motor	AC Synchro. + Boost Converter + Reduction Gear 60kW	←
Battery	Ni-MH 1.3kWh	Lithium-ion 5.2kWh

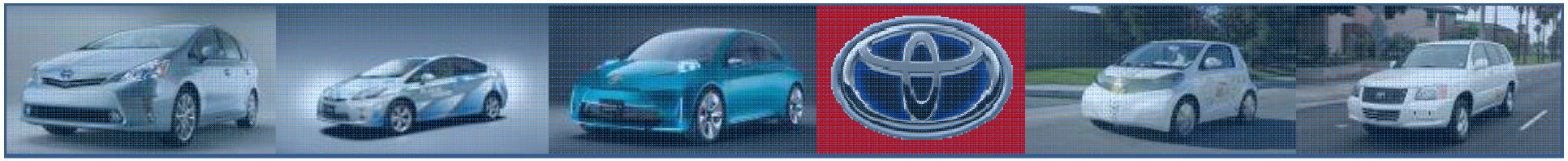


Minimal vehicle modifications and small battery **reduce cost → High Volumes**



PHEV Systems

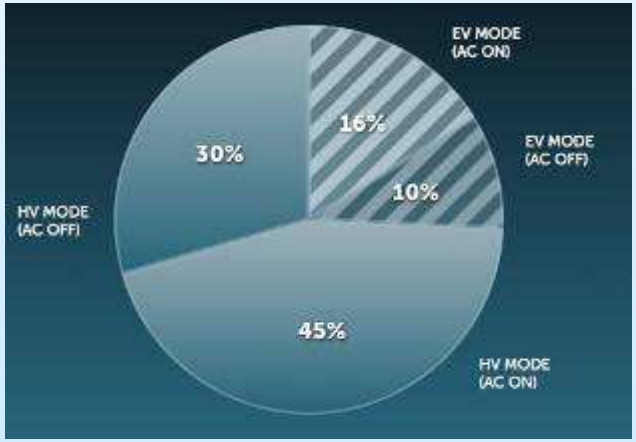




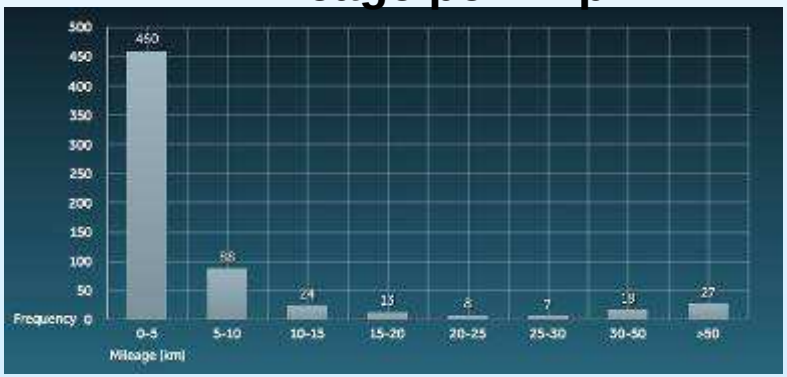
PHEV Demo Program

- ~160 Prius PHEV prototypes are being used by the public in test fleets around the US
- Toyota is posting on the web a summary of the collected data at http://www.toyota.com/esq/#

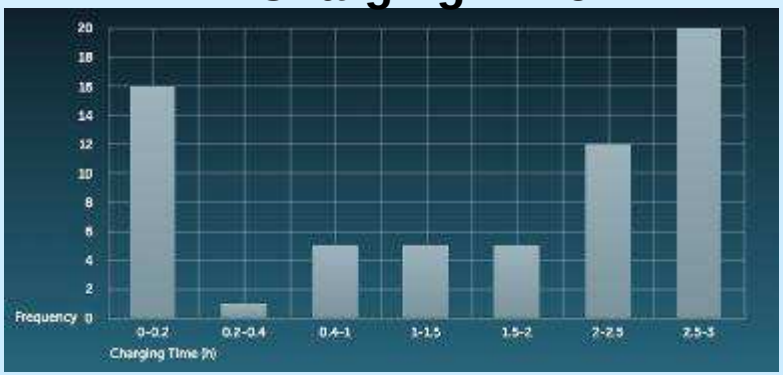
Time in EV vs. HV Mode

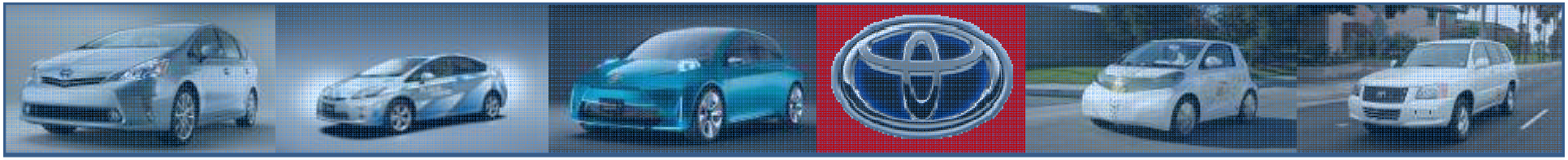


Mileage per Trip



Charging Time





BEVs

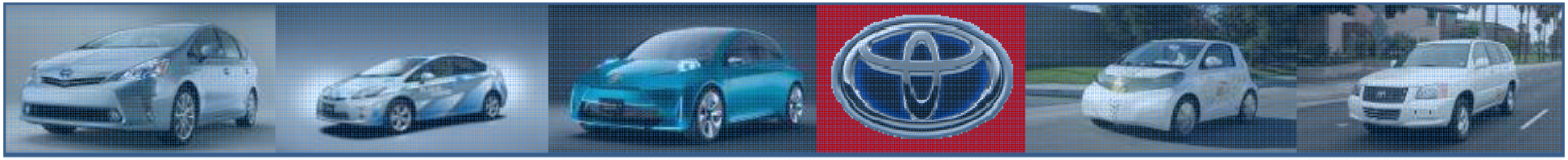
Battery Electric Vehicle (BEV)
[RAV4-EV]

Fuel Cell Hybrid Electric Vehicle
[FCHV-adv]

Hybrid Electric Vehicle (HEV
[Prius]

Plug-in Hybrid Electric Vehicle (PHEV)
[Prius PHEV]

Battery Electric Vehicle (BEV)
[FT-EV]



Battery Electric Vehicles – RAV4-EV Experience

- Offered 1998 – 2003 in CA and AZ
- Over 1200 deployed
- 75-95 mile real-world range
- Most leased to fleet customers
- Only OEM to actually sell EVs
- ~300 still in operation
- Per vehicle marketing cost 15x Prius
- Conclusions (2006)
  - High consumer awareness
  - Small pent-up demand when introduced
  - Low sales, not increasing over time

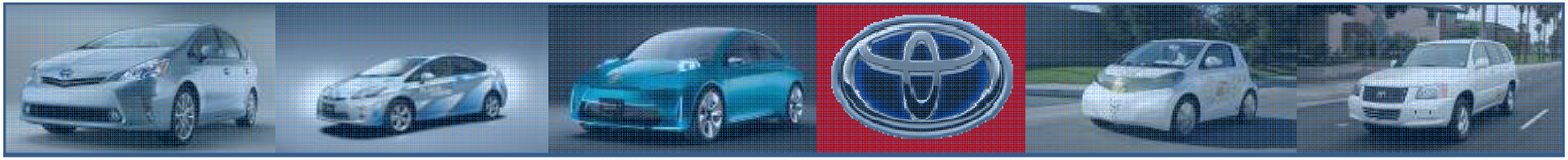
Little evidence to indicate EV demand has grown significantly in last decade

Customer Demographics

Category	RAV4 EV[1]	Prius[2]
% Female	18%	53%
% Male	82%	47%
Median Age	46	52
Median Income	$115,000	$89,286
% Buyers (vs lessors)	22%	98%
% Lessors (vs buyers)	78%	2%

[1] 83% are business owners, executives or professional or technical specia
47% have at least some post-graduate education

[2] Source: CDS Q1-Q2 2002



Toyota BEVs

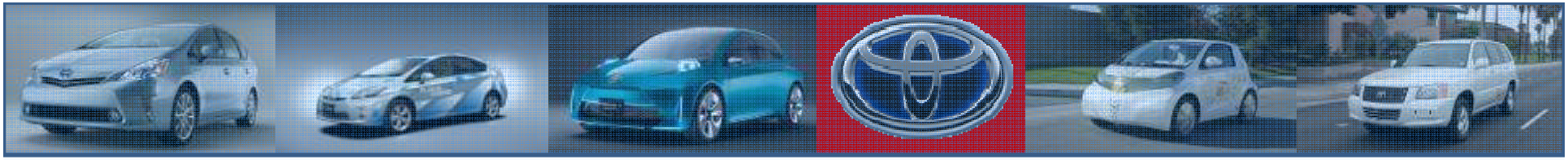
IQ EV - Concept

- Small urban commuter EV
- Range of ~50 miles
- Charging time: ~2.5 hrs / 7.5 hrs (220V / 110V)

RAV4 EV

- Based on current RAV4 ICE
- +100 mile target range
- Powertrain from Tesla
- 2012 Introduction

Range, recharge time & cost limit the market for BEVs



FCHV

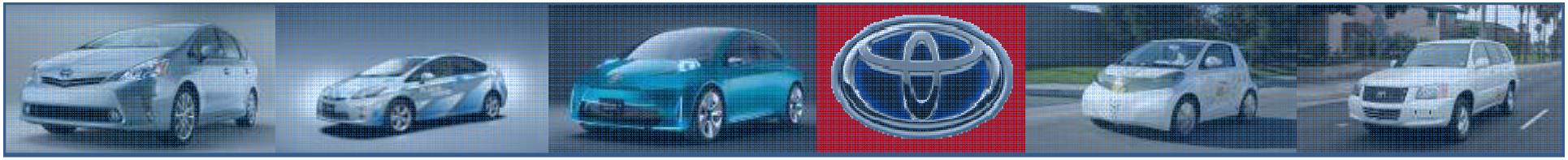
Battery Electric Vehicle (BEV)
[RAV4-EV]

Fuel Cell Hybrid Electric Vehicle
[FCHV-adv]

Hybrid Electric Vehicle (HEV)
[Prius]

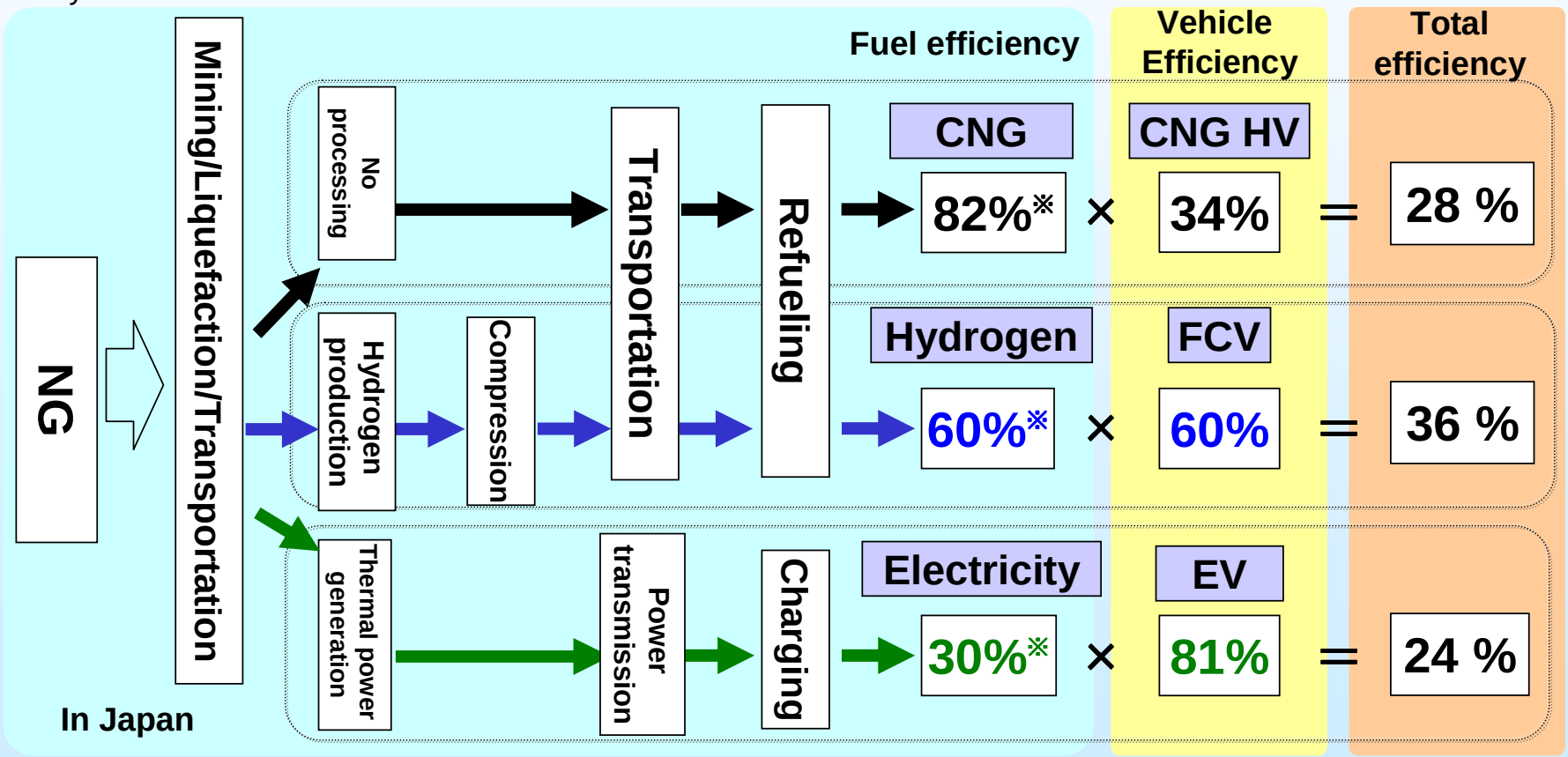
Plug-in Hybrid Electric Vehicle (PHEV)
[Prius PHEV]

Battery Electric Vehicle (BEV)
[FT-EV]



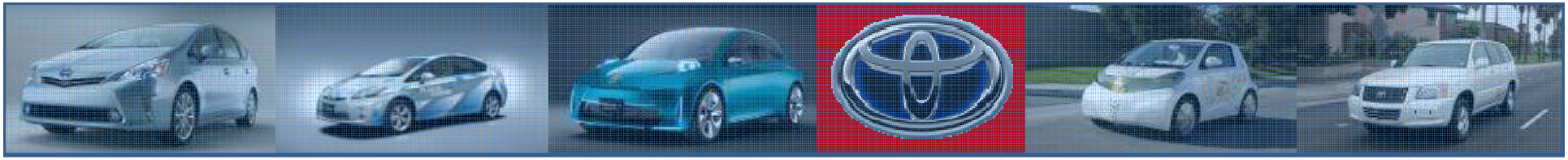
WTW Powertrain Efficiency for Natural Gas

Toyota estimation

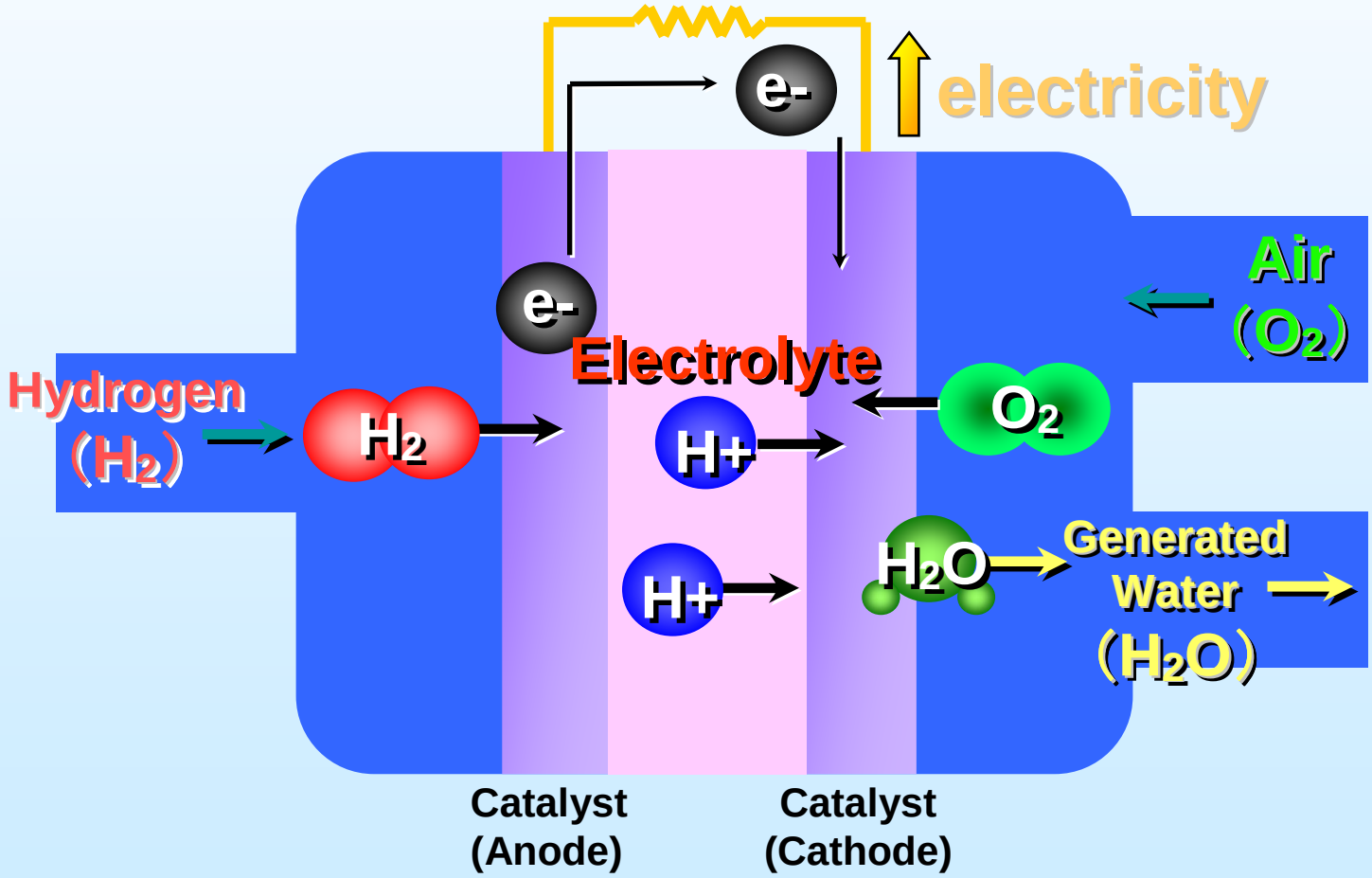


※ JHFC Report

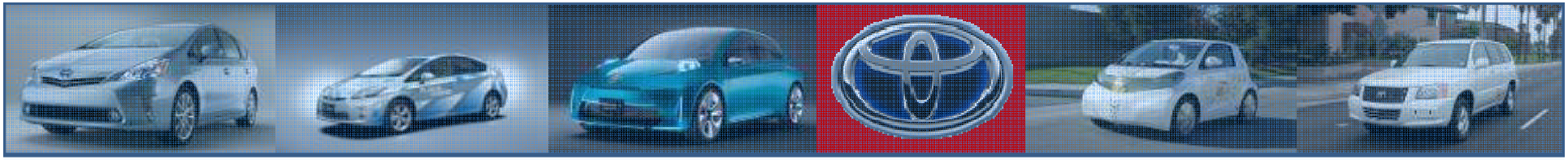
Hydrogen fuel cell vehicles have the best WTW efficiency



How a Polymer Electrolyte Fuel Cell Works



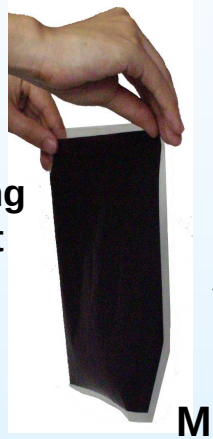
Theoretical efficiency of a fuel cell *DG/DH* = 83 % (Hydrogen)



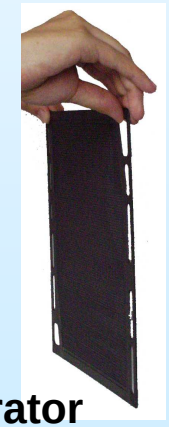
Fuel Cell Structure

Polymer electrolyte membrane

Spreading catalyst



MEA



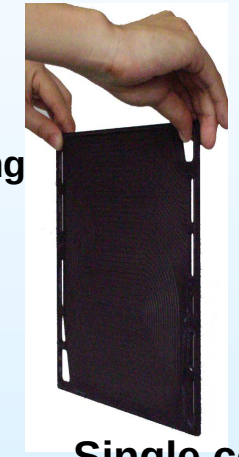
Separator

Separator

MEA

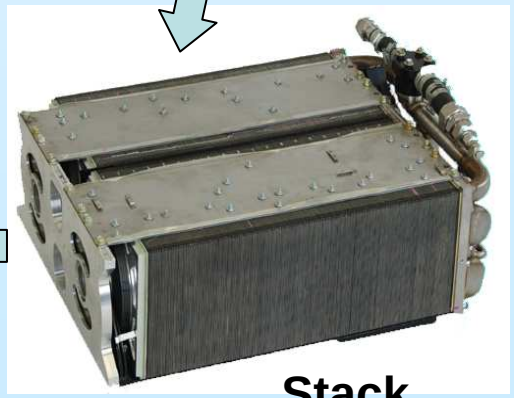
MEA : Membrane Electrode Assembly

Assembling



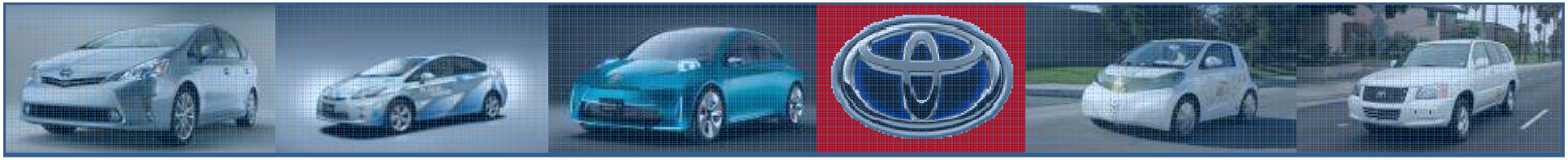
Single cell

Stacking cells



Stack

FC Stack



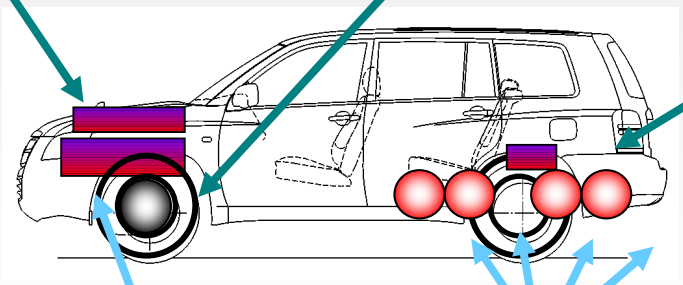
FCHV System Components

Hybrid Technology

Power control unit

Motor

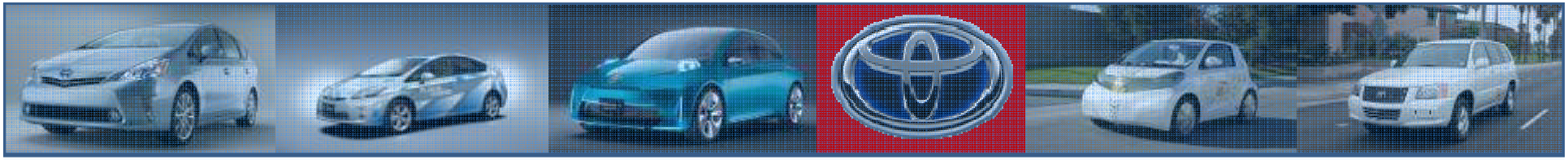
Battery



TOYOTA FC Stack

High pressure hydrogen tank

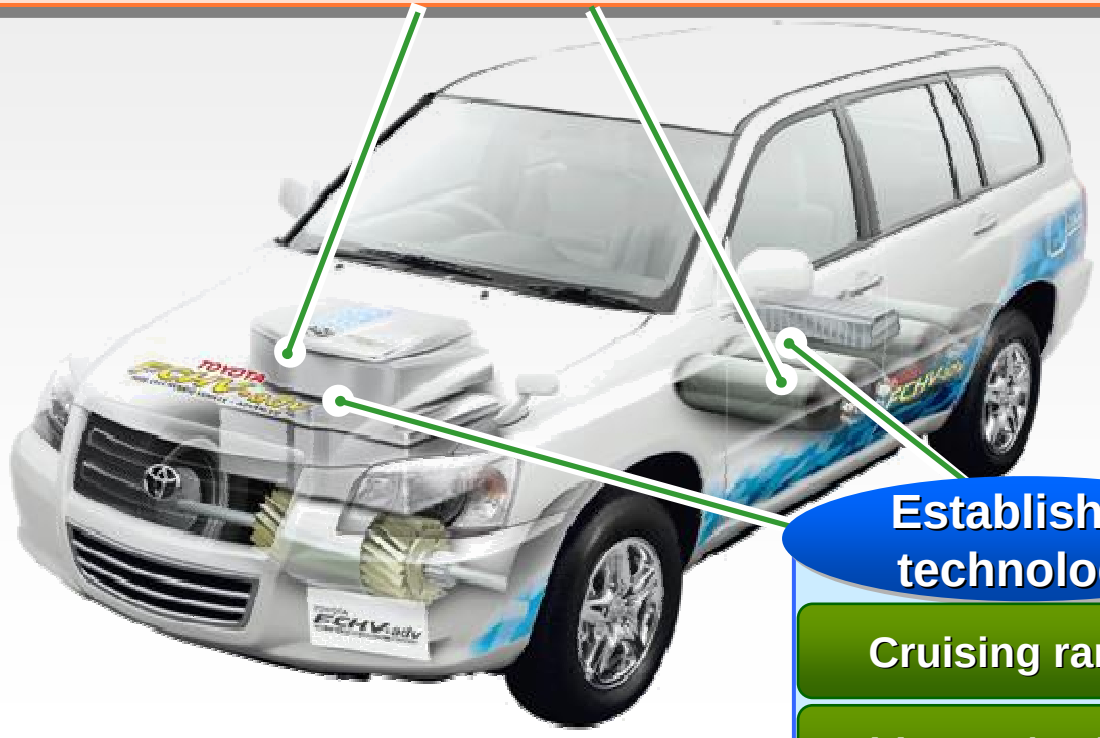
Fuel Cell System Technology



Major Technical Challenges for FC Vehicles

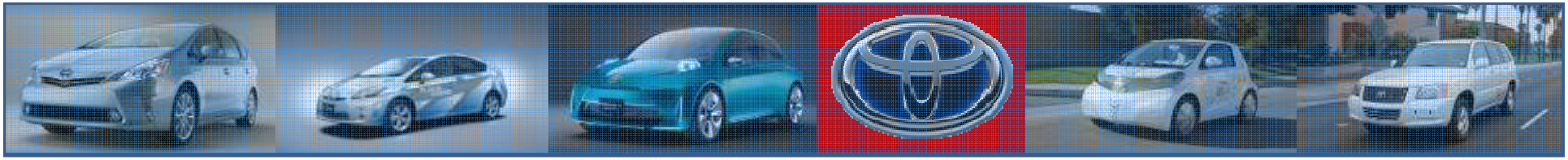
Issues to be solved

Balance cost vs. compactness & performance vs. durability



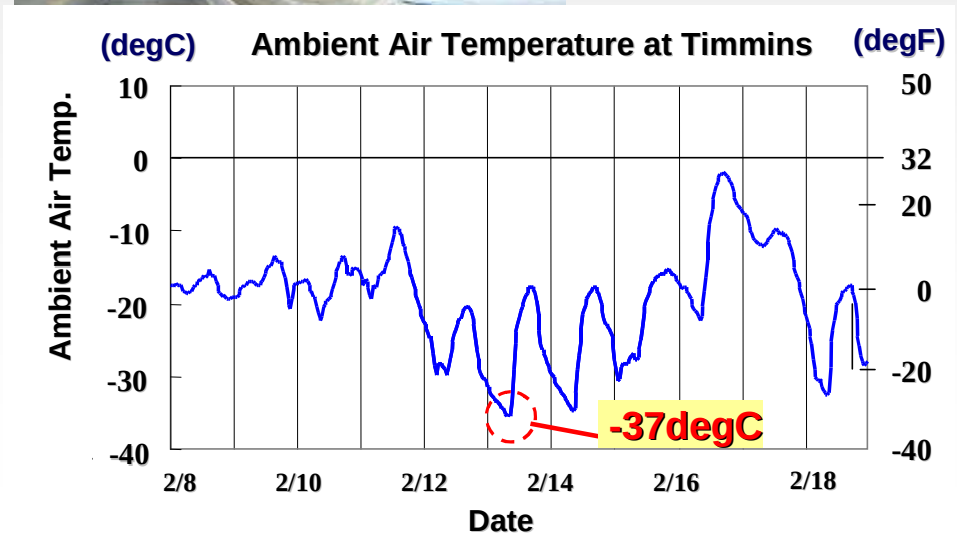
Established technology

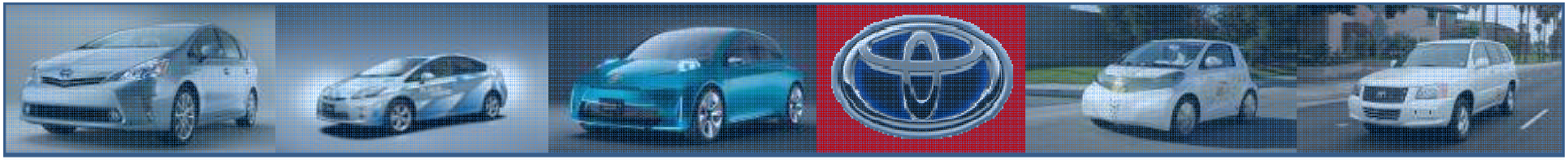
- Cruising range
- Cold start / Driving performance



Cold Start / Driving Capability Verified

Timmins, Canada





Real World Driving Range

System Efficiency Improvement

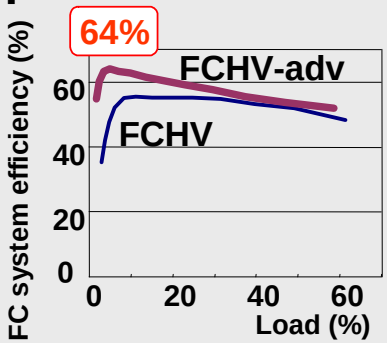
FCHV-adv: improved FC system efficiency at all loads

+

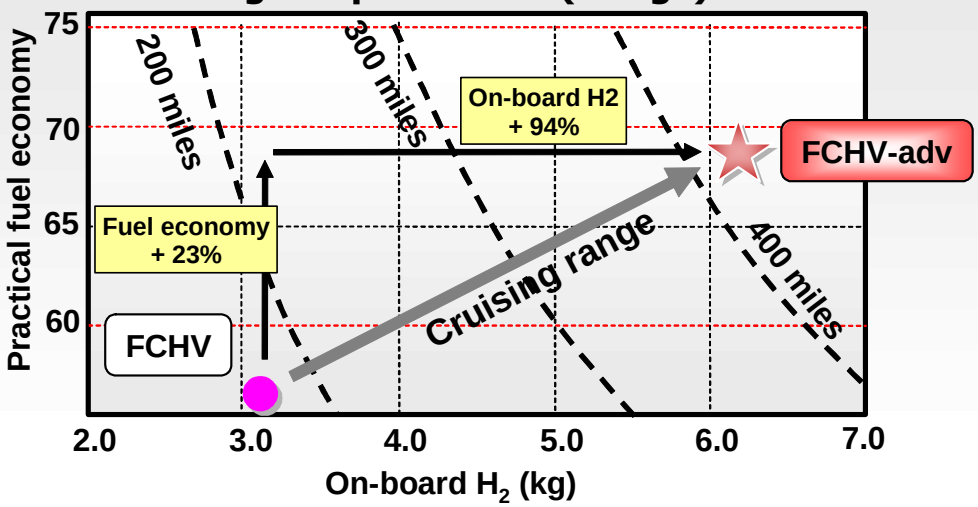
Increased regenerative energy

↓

Improved vehicle efficiency (fuel economy)



Range Improvement (Image)

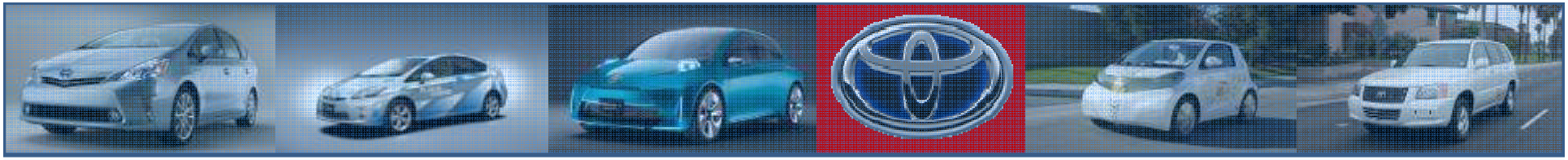


Rush Hour in Los Angeles

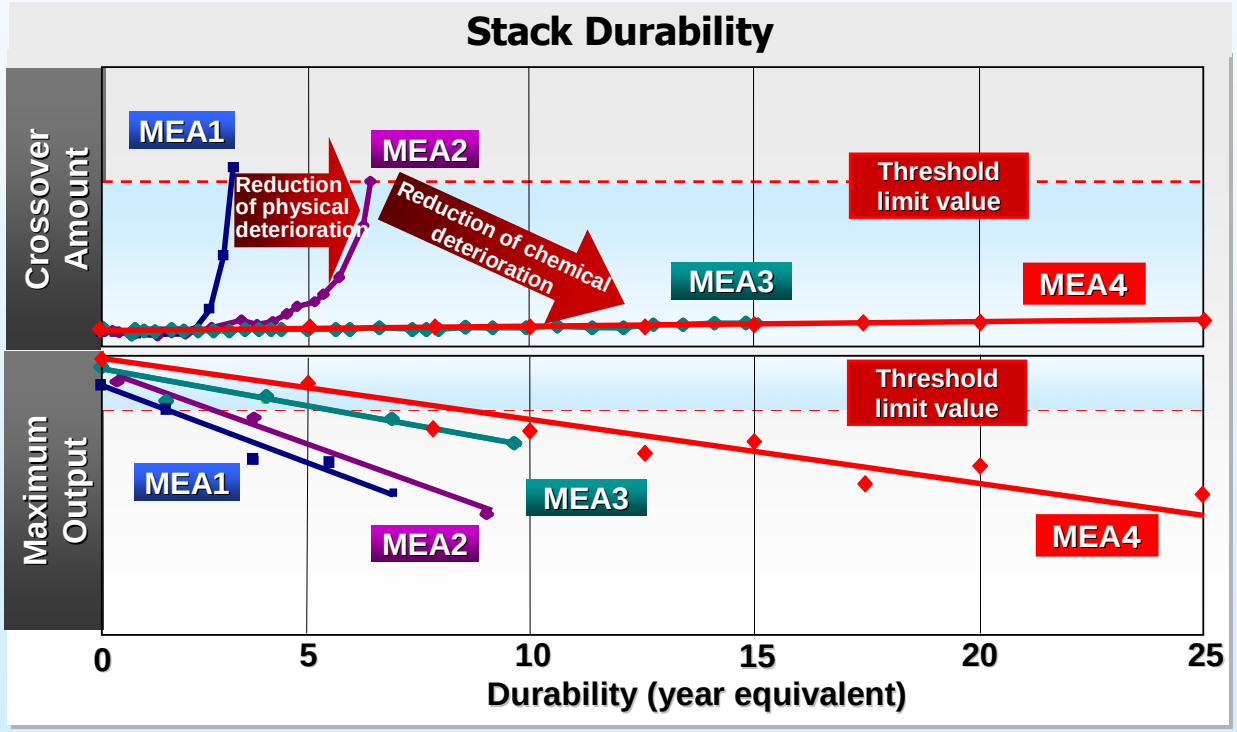
- 2 FCHVs
- Over 400 miles / tank
- 68.3 miles/kg of H2

Fairbanks to Vancouver

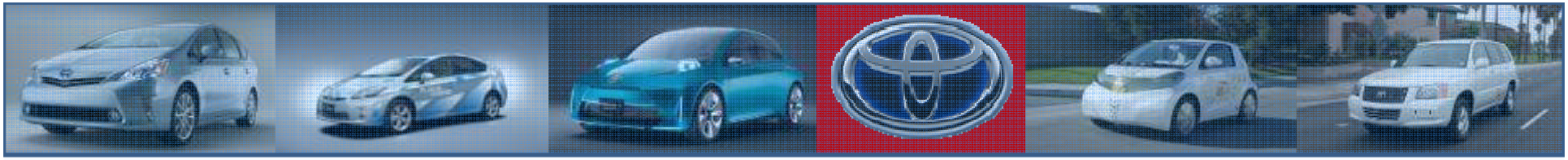
- 2300 miles
- Over 300 miles / tank
- No mechanical problems



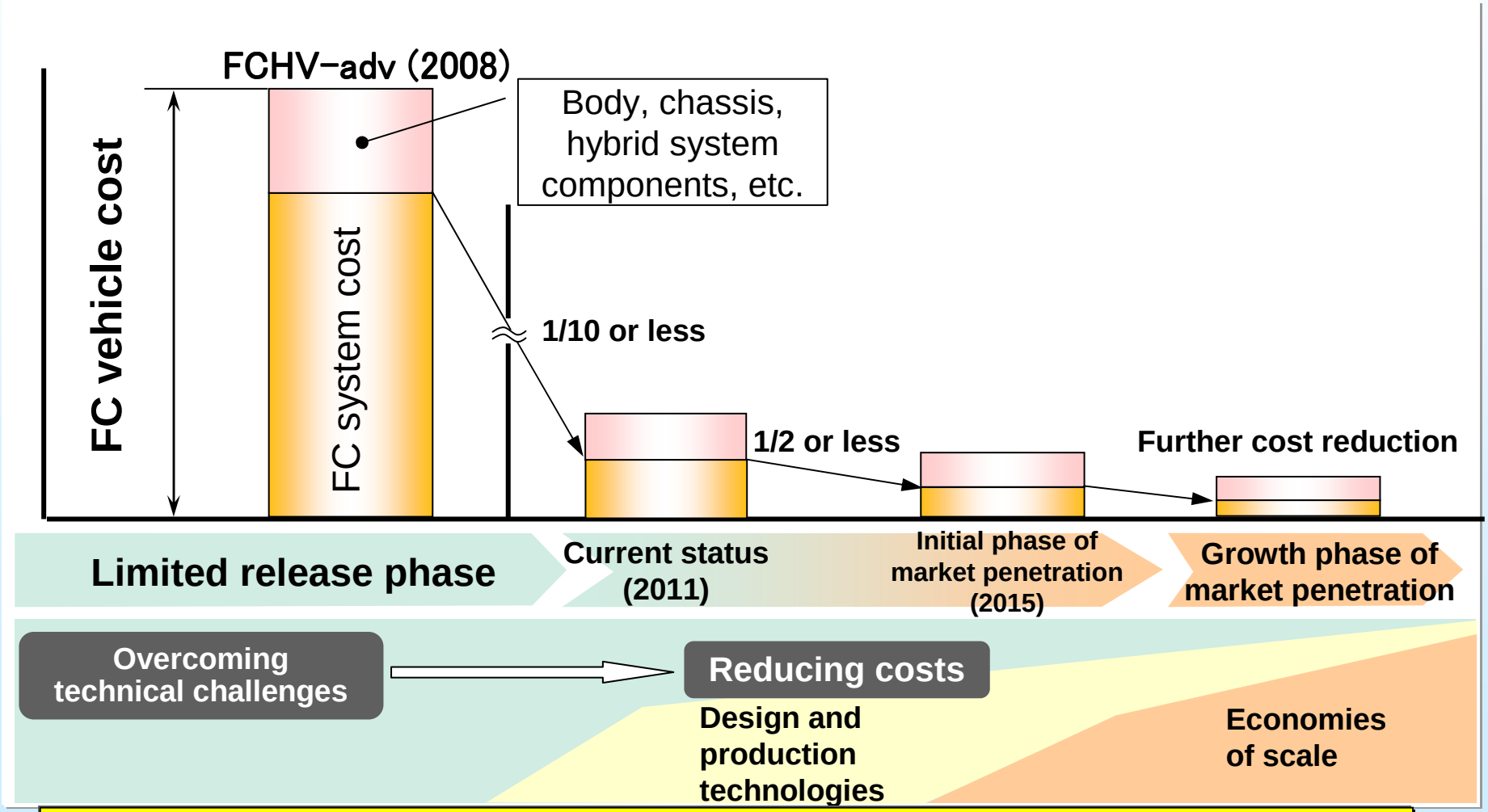
Durability



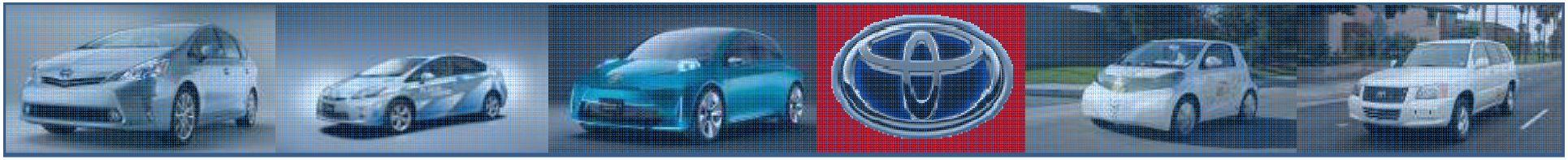
Durability improving, but must advance further before introduction



Cost Reduction

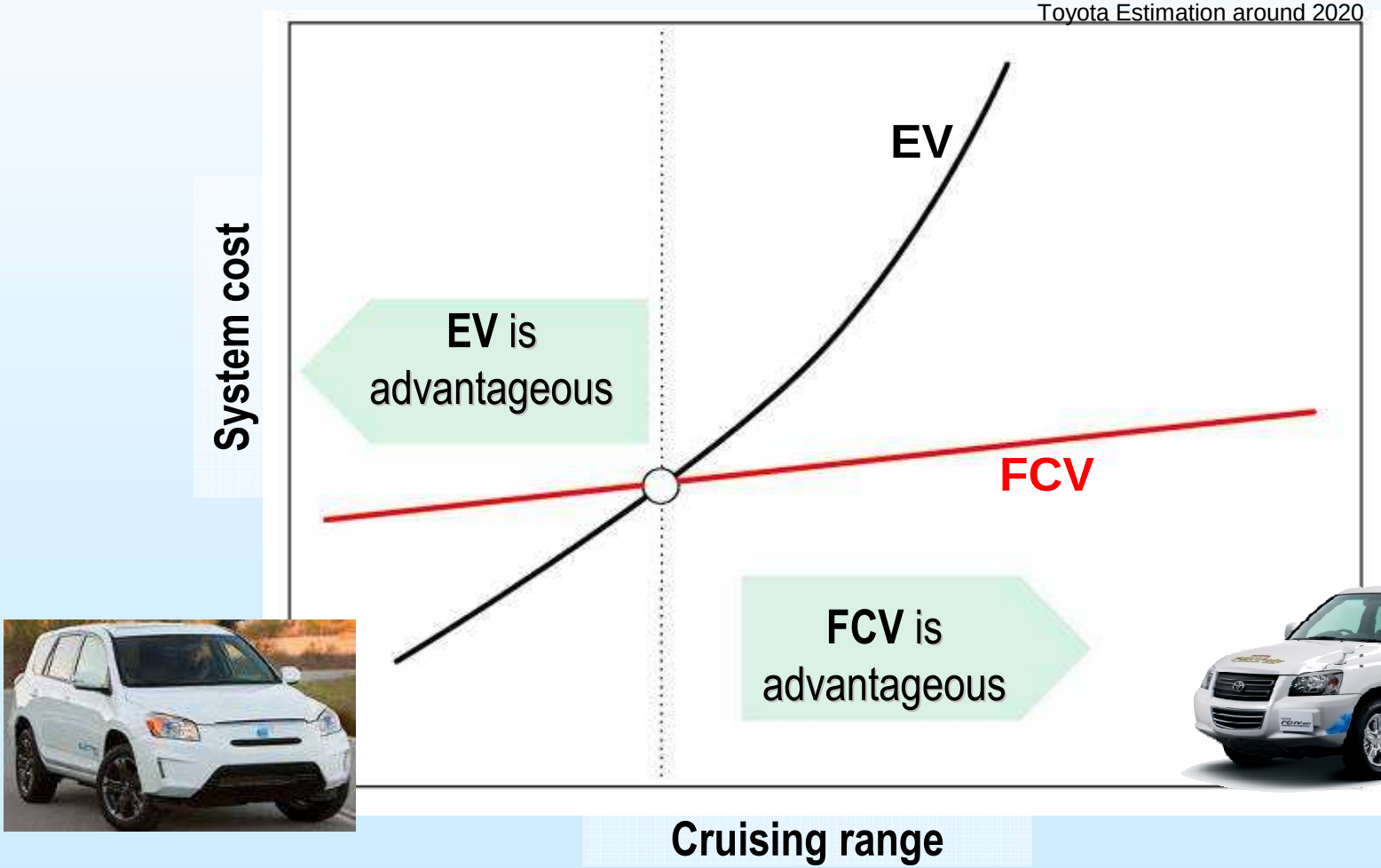


The cost of new FC system is ~1/10 of current FCHV-adv. An additional 50% reduction is targeted for early commercialization.

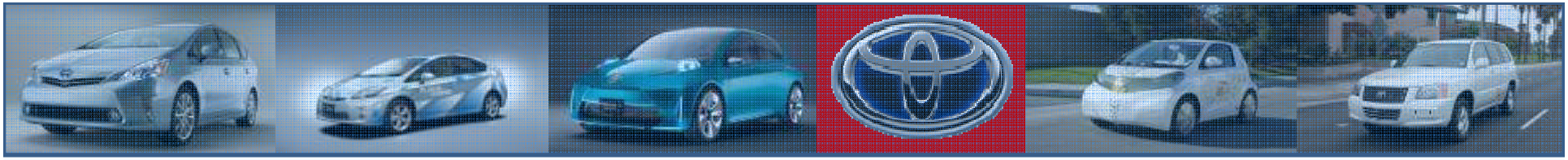


System Cost Comparison

Toyota Estimation around 2020

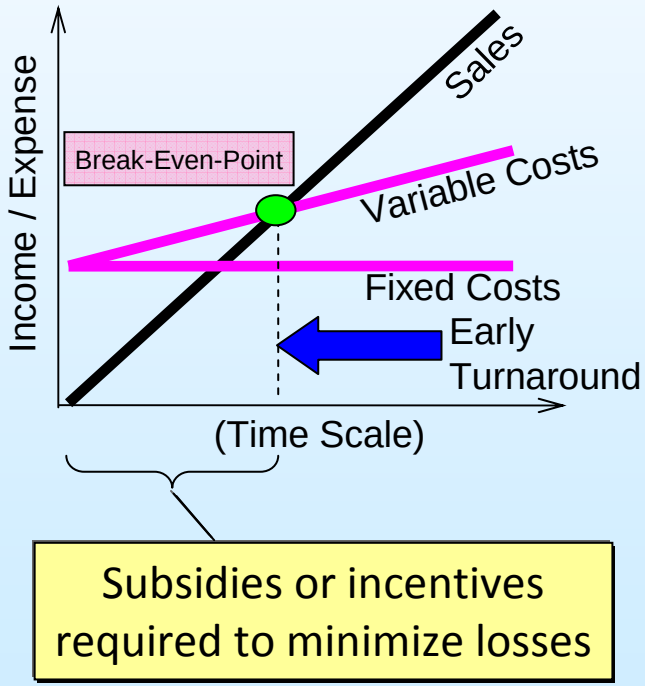


For longer driving ranges, FCVs are a less costly option



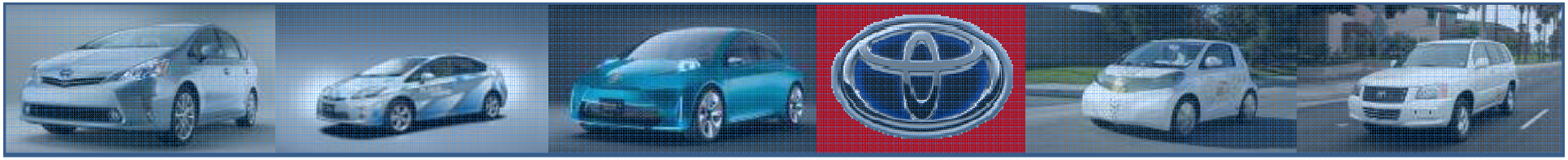
Business Model for Hydrogen Station (Toyota Estimation)

Business Model Image



Profit Factor	Measures	
Sales ↑	FCHV ↑ FC BUS ↑	Deployment into specific regions
Variable Costs ↓	H_2 Cost / Tax ↓ Labor Cost ↓ Maintenance Cost ↓	- Cost Analysis of H_2 - Development of highly durable station
Fixed Costs ↓	Facility Cost ↓ Construction Cost ↓	Development of low cost station

Hydrogen infrastructure is the greatest hurdle for FCV adoption



Scope of Presentation

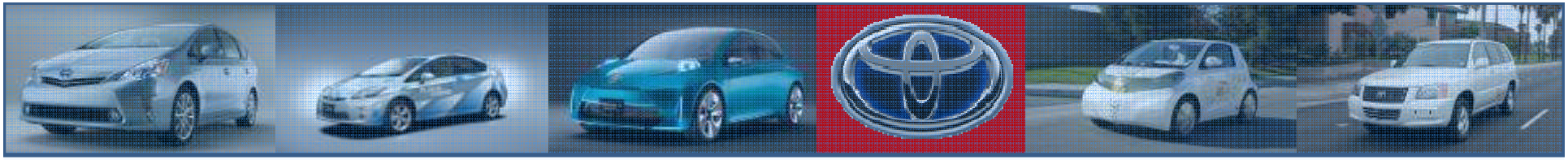
① Drivers of change

② Technology options

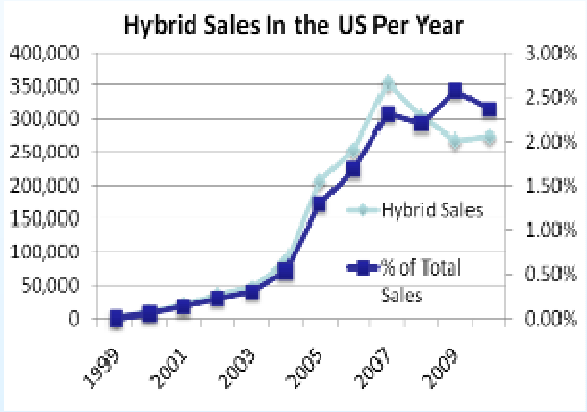
❸ Consumer adoption factors

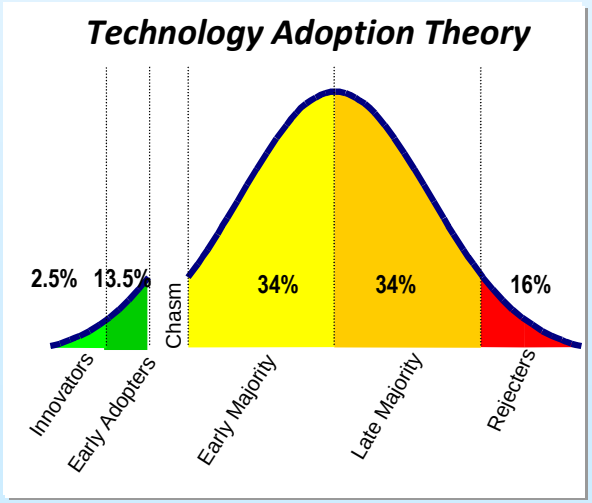
④ Other considerations

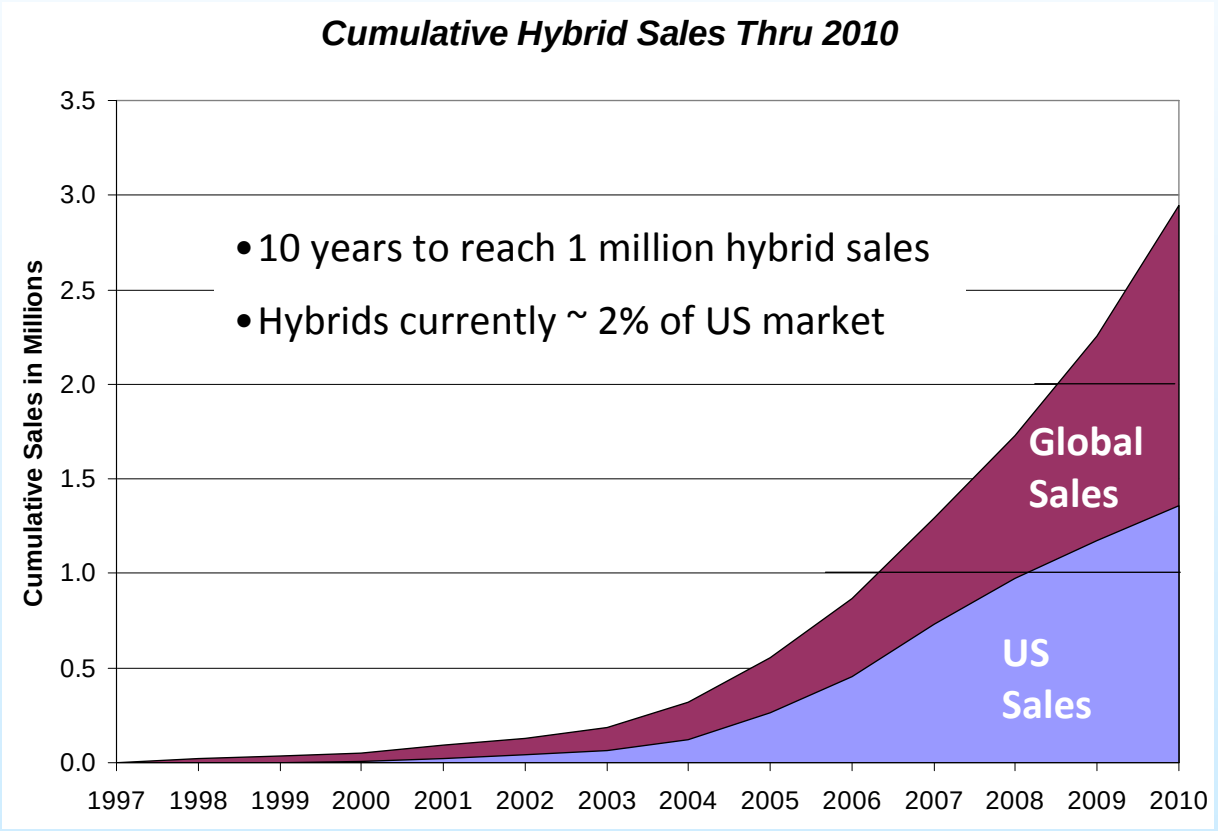
⑤ Conclusions & recommendations



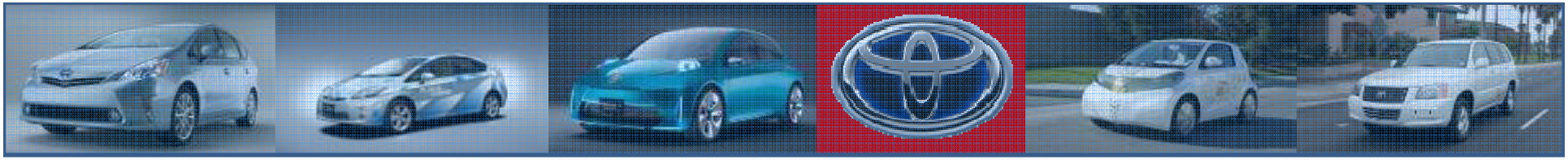
Technology Penetration Takes Time



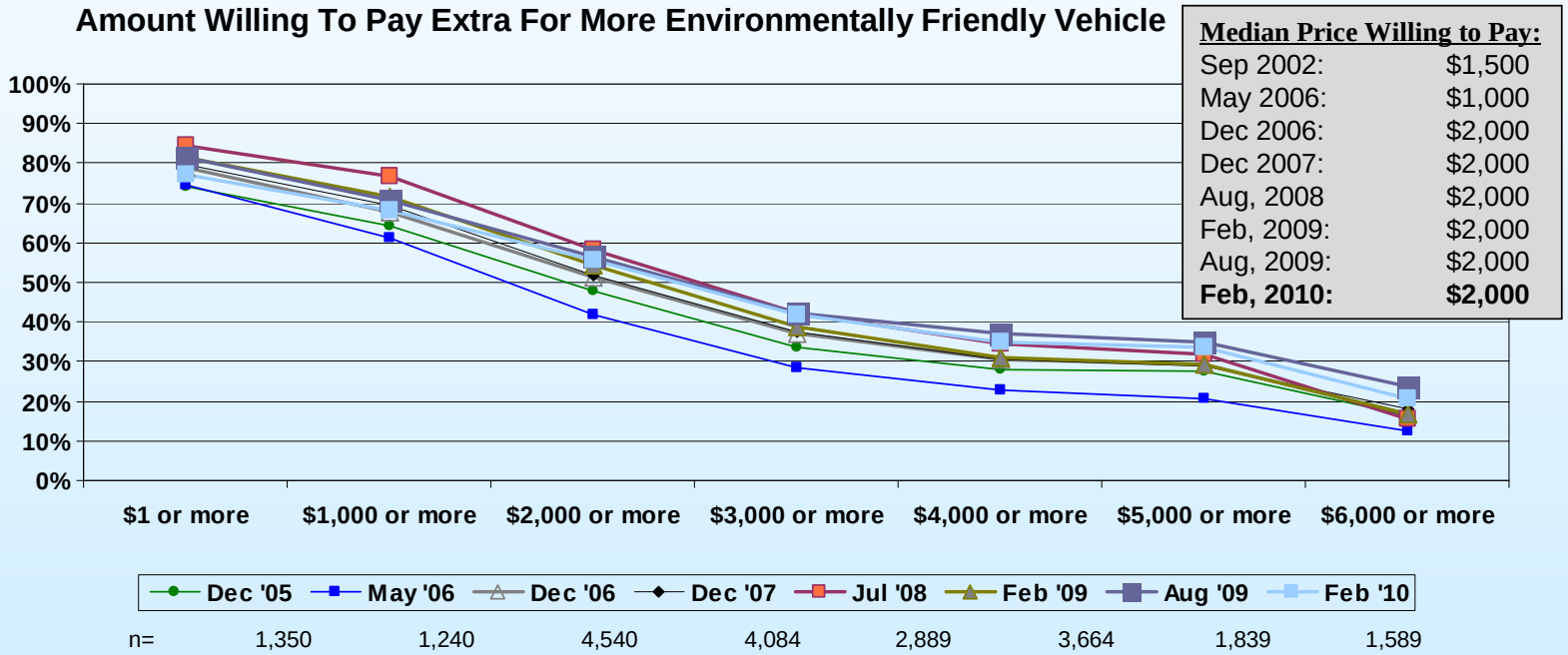




Hybrids continue to sell at niche market volumes



Willingness to Spend for "Green" Vehicle

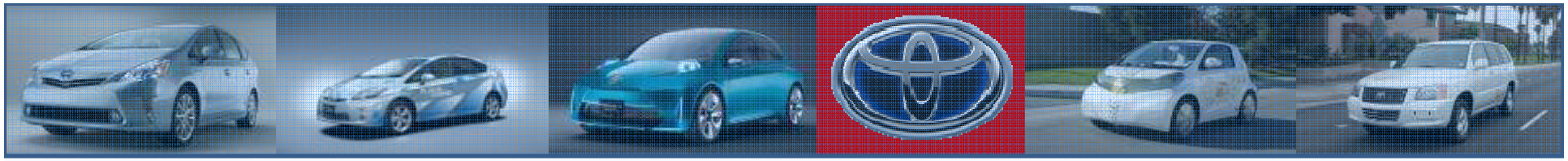


Median Price Willing to Pay:	
Sep 2002:	$1,500
May 2006:	$1,000
Dec 2006:	$2,000
Dec 2007:	$2,000
Aug, 2008	$2,000
Feb, 2009:	$2,000
Aug, 2009:	$2,000
Feb, 2010:	**$2,000**

Q: Think about the vehicle that you would most likely consider purchasing next. If the manufacturer of that vehicle came out with a version of it that was identical in every respect in terms of styling, acceleration, safety, reliability, etc. to the original, except that it was significantly better for the environment, how much extra, if anything, would you be willing to pay for it?

Source: Synovate, Feb 2010

Consumers continue to be unwilling to pay significantly more for a "green" vehicle as the median difference remains constant at a $2K premium.



Scope of Presentation

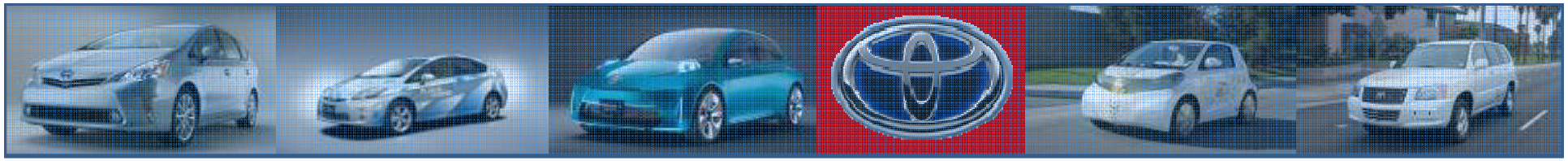
① Drivers of change

② Technology options

③ Consumer adoption factors

④ Other considerations

⑤ Conclusions & recommendations



Comprehensive Measures are Needed

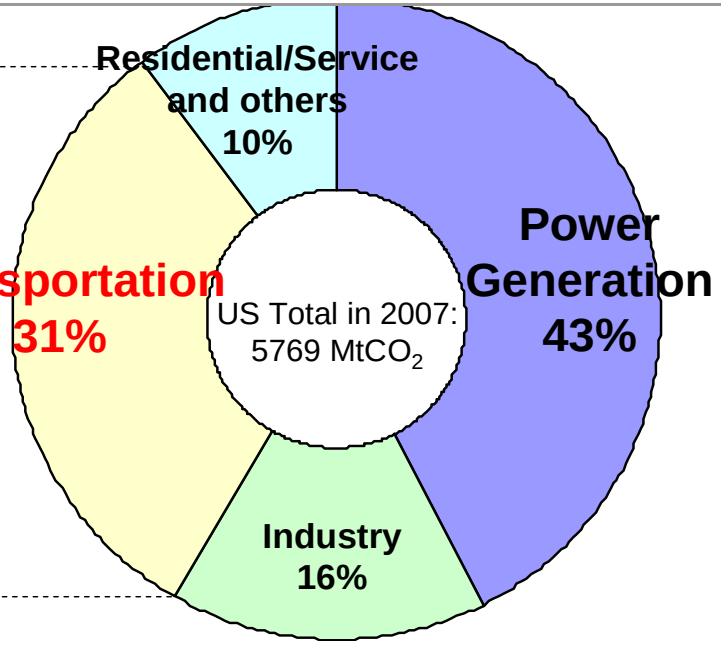
Alt & bio fuels
Traffic congestion
Traveling miles
Vehicle volume
Vehicle efficiency

→ **Road Transportation**

Other transportation

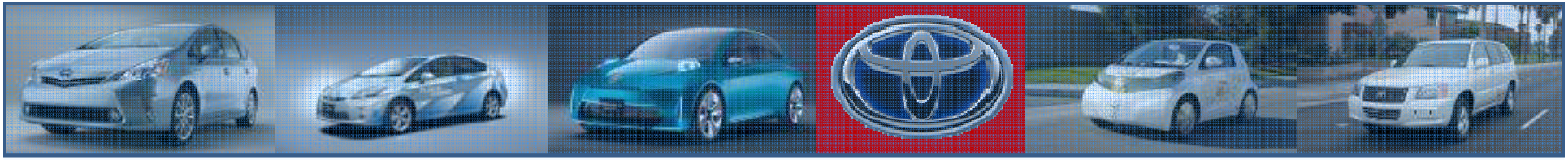
- LDVs consume ~45% of US petroleum
(Current focus gasoline, not petroleum reduction)
- LDVs generate ~19% of US CO2 emission

US CO_2 Emissions for Fuel Combustion



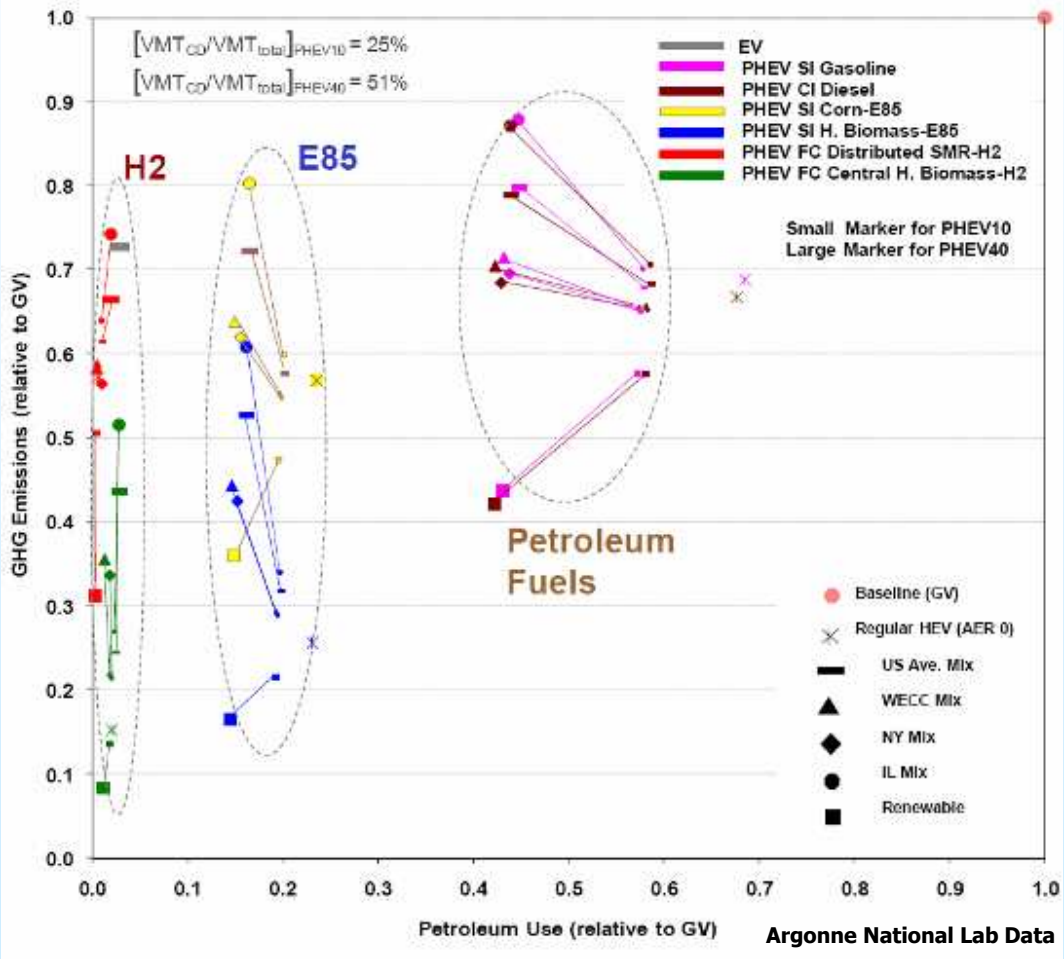
Source: International Energy Agency CO2 emissions fuel combustion 2009 edition

LDV efficiency is only part of the solution.
An **"Integrated Approach"** to GHG reduction in the transport sector is needed.

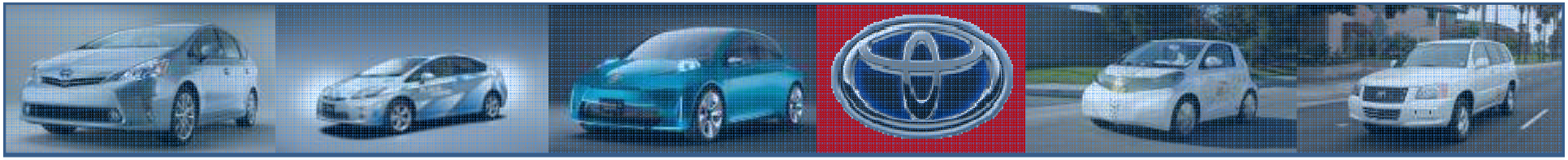


Petroleum & GHG Reduction Potential

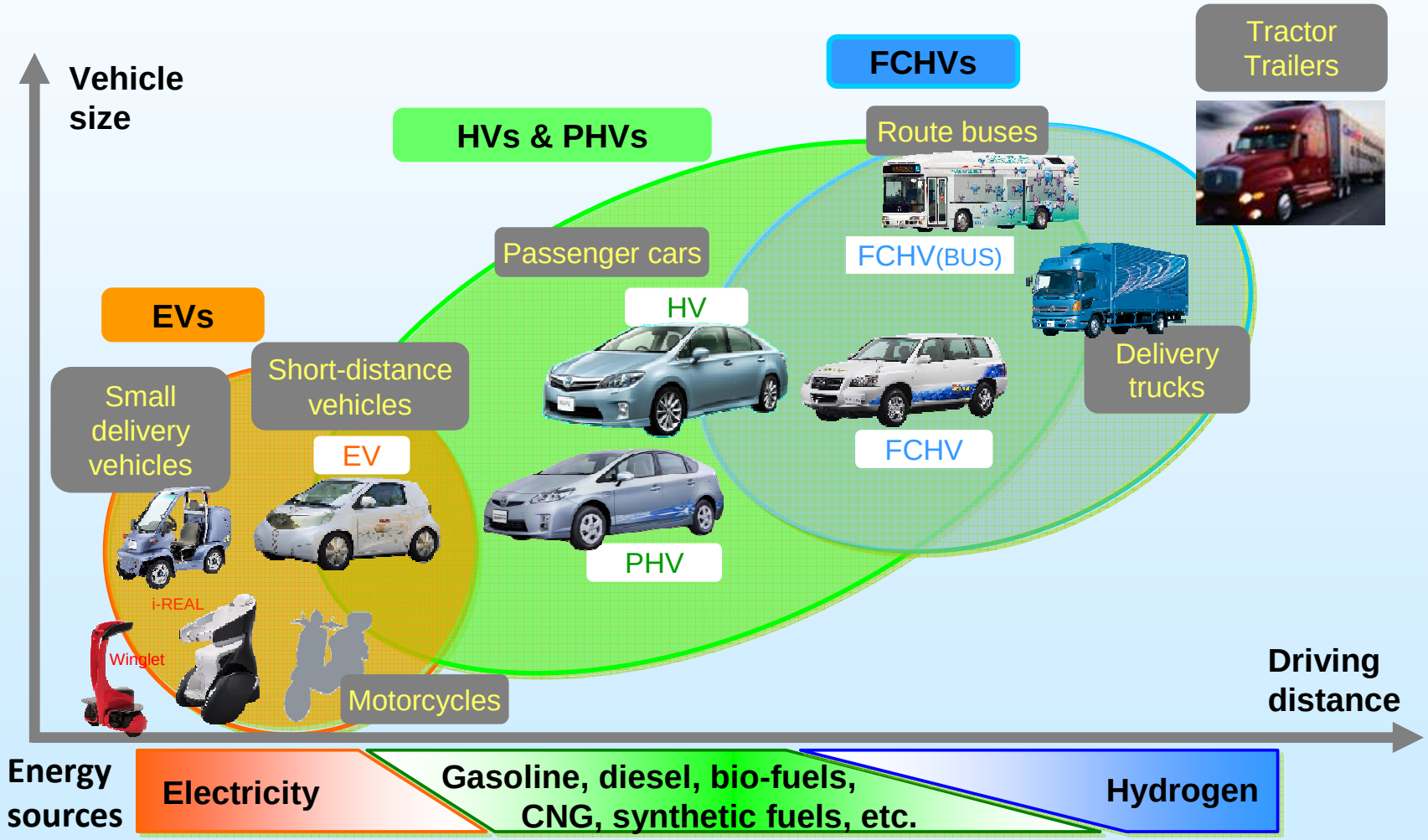
- GHG benefits vary greatly with fuel source
- PHEVs require clean electricity to reduce GHGs (relative to a HEV)



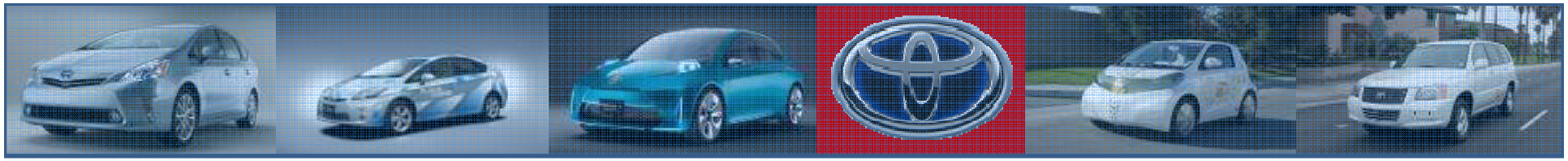
WTW GHG reduction more challenging than petroleum reduction



Shifting Vehicle Size Based on Need



No single powertrain/fuel is optimum of all applications



Conclusions & Recommendations

- Hybridization is the 1st step toward fuel/vehicle diversification
- New technologies and fuels are coming to market today, but will likely take decades to have a major impact
- Petroleum and CO_2 reduction strategies may not be synergistic
- GHG and petroleum reduction policy/regulation must include:
  - All economic sectors
  - All petroleum products, i.e. gasoline, diesel, jet
  - Fuel availability along with vehicle technology, i.e. hydrogen for FCVs
  - Integrated Approach to complement vehicle improvements, i.e. ITS
- Employ stable technology neutral policies and regulations
- Consumers, not policymakers, select the winning technology